Stability Parameters for Grain Yield and its Component Traits in Maize Hybrids of Different FAO Maturity Groups

Parametri stabilnosti prinosa zrna i komponenti prinosa hibrida kukuruza različitih FAO grupa zrenja

Dragan S. DJUROVIĆ, Milomirka R. MADIĆ*, Nikola R. BOKAN, Vladeta I.STEVOVIĆ, Dalibor D. TOMIĆ and Snežana T. TANASKOVIĆ*

University of Kragujevac, Faculty of Agronomy, Cara Dušana 34, 32000 Čačak, Serbia.
stanasko@kg.ac.rs or mmadic@kg.ac.rs *correspondence

Abstract

An objective evaluation of maize hybrids in intensive cropping systems requires identification not only of yield components and other agronomically important traits but also of stability parameters. Grain yield and its components were assessed in 11 maize hybrids with different lengths of growing season (FAO 300-700 maturity groups) using analysis of variance and regression analysis at three different locations in Western Serbia. The test hybrids and locations showed significant differences in grain yield, grain moisture content at maturity, 1,000-kernel weight and ear length. A significant interaction was observed between all traits and the environment.
The hybrids with higher mean values of the traits, regardless of maturity group, generally exhibited sensitivity i.e. adaptation to more favourable environmental conditions as compared to those having lower mean values. Regression coefficient (b_i) values for grain yield mostly suggested no significant differences relative to the mean. The medium-season hybrid gave high yields and less favourable values of stability parameters at most locations and in most years, as compared to medium-late hybrids.
As compared to medium-early hybrids, medium-late hybrids (FAO 600 and 700) mostly exhibited unfavourable values of stability parameters i.e. a specific response and better adaptation to favourable environmental conditions, and gave higher average yields. Apart from producing lower average yields, FAO 300 and 400 hybrids showed higher yield stability as compared to the other hybrids tested.
Medium-late hybrids had higher yields and showed a better response to favourable environmental conditions compared to early-maturing hybrids. Therefore, they can be recommended for intensive cultural practices and low-stress environments.

Due to their more favourable stability parameter values, medium-early hybrids can be recommended for low-intensity cultural practices and stressful environments.

Keywords: maize, hybrids, stability parameters, grain yield, yield components

Rezime

Za intenzivno gajenje hibrida kukuruza neophodno je, pored komponenti prinosa i drugih agronomski važnih osobina biljke, za objektivnu ocenu njihovih stvarnih vrednosti utvrditi i parametre stabilnosti. U radu je analiziran prinos zrna i komponente prinosa kod 11 hibrida kukuruza različite dužine vegetacije (FAO grupa zrenja 300-700) metodom analize varijanse i regresionom analizom na tri različita lokaliteta zapadne Srbije.

Između pojedinih hibrida kao i lokaliteta postojale su značajne razlike u pogledu prinosa zrna, sadržaja vlage u zrnu u vreme zrenja, mase 1000 zrna i dužine klipa. Sva analizirana svojstva su pokazala i značajnu interakciju sa spoljnom sredinom.

Hibridi sa većim srednjim vrednostima analiziranih osobina, nezavisno od pripadnosti grupi zrenja, generalno su ispoljili bolju adaptiranost na povoljnije uslove sredine u odnosu na hibride sa nižim srednjim vrednostima.

Vrednosti regresionog koeficijenta (b_i) za prinos zrna ukazuju da uglavnom nisu utvrđene značajne razlike u odnosu na srednju vrednost. Hibrid srednje dužine vegetacije (HY06) u svim lokalitetima i godinama postigao je visoke prinose uz nepovoljnije vrednosti parametara stabilnosti u odnosu na hibride duže vegetacije.

Nepovoljne vrednosti patrametara stabilnosti registrovane su kod hibrida kasnijih grupa zrenja u odnosu na ranije grupe zrenja to jest FAO 600-700 vs FAO 300-400. Kod kasnijih hibrida utvrđena je specifična reakcija i bolja adaptacija na povoljnije uslove spoljašnje sredine, što je rezultiralo i višim prosečnim prinosima. Kod ovih hibrida nivo prinosa nije mogao biti ugrožen prinosom ranijih hibrida. Hibridi iz FAO grupe 300 i 400, uz niže prosečne prinose, su pokazali veću stabilnost prinosa u odnosu na ostale ispitivane hibride.
Srednje kasni hibridi imali su veći prinos i bolju reakciju na povoljne uslove sredine u odnosu na hibride ranijih grupa zrenja, tako da se mogu preporučiti za uslove intezivne agrotehnike i manje stresne sredine. Zbog povoljnijih vrednosti parametara stabilnosti, srednje rani hibridi bi se mogli prepotučiti za gajenje u uslovima nižeg nivoa agrotehnike i za stresne sredine.

Ključne reči: kukuruz, hibridi, parametri stabilnosti, prinos zrna, komponente prinosa

Detailed abstract

Za objektivnu ocenu stvarnih vrednosti hibrida kukuruza neophodno je, pored prinosa zrna, komponenti prinosa i drugih agronomski važnih osobina proceniti i njihovu stabilnost. U radu je analiziran prinos zrna i komponente prinosa kod 11 hibrida kukuruza različite dužine vegetacije (FAO grupa zrenja 300-700) metodom analize varijanse i regresionom analizom. Hibridi su ispitivani u uporednim poljskim ogledima u toku 2005 i 2006 godine na tri lokaliteta Zapadne Srbije, bez navodnjavanja, na zemljištima različitih proizvodnih sposobnosti: Parmenac (tip zemljišta aluvijum), Mojsinje (tip zemljišta vertisol) i Tavnik (tip zemljišta pseudoglej).

Na svim lokalitetima ogledi su postavljeni po slučajnom blok sistemu sa četiri ponavljanja.

Svaki hibrid u svakom ponavljanju ručno je zasejan u četiri reda, na međurednom rastojanju 0,7m. U redu je 17 kućica na rastojanju od 0,57m sa po dve biljke u kućici. Na ovaj način je postignuta gustina setve od 50.000 biljaka ha^{-1}. U uzorcima za merenja i analize uzeta su dva srednja reda, a krajnje kućice su isključene iz uzorkovanja (ukupno 60 biljaka).

Posle nicanja usev je proređen na stalni, planirani broj biljaka. Setve je obavljena u provoj polovini aprila u obe godne na svim lokalitetima. U toku vegetacije primenjene su uobičajene agrotehničke mere. Berba je obavljena ručno u fiziološkoj zrelosti. Nakon berbe sa svake parcele izmeren je prinos klipova (60 biljaka) i preračunat prinos zrna po ha^{-1} sa 14% vlage. U laboratoriji je utvrđen sadržaj vlage u zrnu u berbi (iz istog uzorka, u %), dužina klipa (cm) i masa 1000 zrna (g) za sve hibride po ponavljanjima (odbrojavanjem četiri probe po 500 zrna i preračunavanjem). Dobijeni rezultati obrađeni su metodom analize varijanse faktorijalnog ogleda uz korišćenje F i LSD testa, a parametri stabilnosti su procenjeni metodom regresione analize (Eberhart i Russell, 1966).

Između pojedinih hibrida kao i lokaliteta postojale su značajne razlike u pogledu prinosa zrna, sadržaja vlage u zrnu u vreme zrenja, mase 1000 zrna i dužine klipa. Sva analizirana svojstva pokazala su značajnu interakciju sa spoljnom sredinom.

Hibridi sa većim srednjim vrednostima analiziranih osobina, nezavisno od pripadnosti grupi zrenja, generalno su ispoljili senzitivnost odnosno adaptiranost na povoljnije uslove sredine u odnosu na hibride sa nižim srednjim vrednostima.

Vrednosti regresionog koeficijenta (b_i) za prinos zrna ukazuju da kod većine hibrida nisu utvrđene značajne razlike u odnosu na srednju vrednost (b_i=1). Hibrid srednje dužine vegetacije (HY06) u svim lokalitetima i godinama postigao je visoke prinose uz nepovoljnije vrednosti parametara stabilnosti u odnosu na hibride duže vegetacije.

Nepovoljne vrednosti patrametara stabilnosti registrovane su kod hibrida kasnijih grupa zrenja u odnosu na ranije grupe zrenja to jest FAO 600-700 vs FAO 300-400. Kod kasnijih hibrida utvrđena je specifična reakcija i bolja adaptacija na povoljnije uslove spoljašnje sredine, što je rezultiralo i višim prosečnim prinosima. Kod ovih hibrida nivo prinosa nije mogao biti ugrožen prinosom ranijih hibrida. Hibridi iz FAO grupe 300 i 400, uz niže prosečne prinose, su pokazali veću stabilnost prinosa u odnosu na ostale ispitivane hibride.

Introduction

Identification of genotypes with a high potential for yield and stability across environments is an essential task in plant breeding. Identifying stable genotypes is often complicated by the presence of genotype x environment interaction (GEI). Significant GEI results from changes in the relative ranking of genotype performance across environments, and it affects breeding progress (Pham and Kang, 1988). Moreover, the high value of GEI is often associated with a low correlation between genotypic and phenotypic values, thereby reducing the selection progress.
A genotype is considered stable if its performances are relatively constant across environments. Becker and Leon (1988) established a biological or static concept of stability under which a stable genotype displays a minimal variance (for yield, for instance) across different environments. However, this concept is of less importance to breeders and agronomists, who prefer genotypes with high yields and the potential to respond positively to agronomic inputs and favourable environmental conditions (Becker, 1981). Under dynamic stability, a genotype or cultivar attains a constant high yield response to changes in the environment. Therefore, when we consider yield stability of a certain genotype, we have to bear in mind that stability can be a

consequence of various factors, such as tolerance to drought or resistance to the most important diseases or pests (Babic et al. 2010, 2013). Also, the quality of corn cob and influence in nutritive value of kernel is highly impacted by economically important pest, *Ostrinia nubilalis* (Keszthelyi and Takács, 2002) *and Diabrotica virgifera* (Tóth, 2005) as a result of growing damage.

A number of stability analyses using GEI have been proposed to identify genotypes exhibiting good performance or high yields under different environmental conditions. Stability measures are based either on regression analysis or on principal component analysis (Bernardo, 2002). Some of the most common stability parameters include Finlay and Wilkinson's (1963) regression coefficient, deviation from regression (Eberhart and Russsell, 1966), stability variance (Shukla, 1972), yield stability parameter (Kang, 1993) and AMMI model (Gauch, 1992).

The model proposed by Eberhart and Russell (1966) has been widely employed in the last several decades mostly due to the classification of variation in genotype performance into predictable (regression) and unpredictable (deviation from regression) components. Hypothetically, Eberhart and Russell's method evaluates both yield (regression) and stability (deviation from regression), with regression being predictable and controlled to a certain extent through the selection of genotypes for specific locations. In this model, a regression coefficient greater than 1.0 indicates superior performance compared to the overall average of all genotypes. However, Alwala et al. (2010) reported that the regression coefficient indicates the "suitability"of the model rather than genotype performance per se. Moreover, if the regression coefficient does not show significant differences across genotypes, regression lines can be grouped, with only deviation from regression being used as a stability parameter for genotype classification. Using this criterion, Flores et al. (1998) classified Eberhart and Russell's model into Group III of stability parameters, where genotypic stability is measured independently of yield level. Lin et al. (1986) defined the GEI model in a regression analysis as a descriptive model based on the set of data, rather than a model to be used for prediction purposes, with the independent variable determined before the experiment begins. However, the fact that the independent variable (environmental index) in this model can be used before the experiment may be considered a limitation to interpreting deviations from regression as being a measure of cultivar stability.

Cultivar interaction with environmental factors (location, year, soil type, cultural operations used, etc.) is an important consideration for plant breeders. The statistically non-additive genotype x environment interaction suggests dependence of yield differences among cultivars on the environment (Yue et al. 1997). A strategy to reduce GEI involves selecting cultivars with a better stability across a wide range of environments in order to better predict their behaviour (Eberhart and Russell, 1966; Tai, 1971). The model proposed by Eberhart and Russell (1966) interprets the variance of deviations from regression as a measure of cultivar stability and the linear regression coefficient (*bi*) as a measure of cultivar adaptability.

An objective evaluation of maize hybrids in intensive cropping systems requires identification not only of yield components and other agronomically important traits but also of stability parameters. The objective of this study was to evaluate grain yield and its components in maize hybrids with different lengths of growing season (FAO 300-700 maturity groups) using analysis of variance and regression analysis.

Short-season hybrids generally have a lower genetic potential for yield as compared to medium-late hybrids, but show more favourable values of stability parameters. The results obtained should point to the possibility of using short-season hybrids instead of medium-late ones, given the balance between yield, yield components and other agronomically important traits, on the one hand, and values of stability parameters, on the other.

Materials and methods

Eleven double-way maize hybrids developed at the Zemun Polje Maize Research Institute were assessed. The hybrids belong to different maturity groups, viz. medium-early hybrids FAO 300-400 (HY01, HY02, HY03 and HY04), medium-season hybrids FAO 500 (HY05, HY06 and HY07), and medium-late hybrids FAO 600-700 (HY08, HY09, HY10 and HY11).

The hybrids were tested in parallel field experiments during 2005 and 2006 at three locations in West Serbia: Mojsinje (N 43^{o}87' E 20^{o}47'), Parmenac (N 43^{o}89' E 20^{o}29') and Tavnik (N 43^{o}83' E 20^{o}59').

Given the relatively narrow geographic area, the locations selected for the study are representative of the major types of soils used for maize production in this region. The soils at these locations differed in type and general fertility. The soil in Mojsinje is a heavy-textured vertisol acid in reaction (pH_{H2O} 5.1) with a medium organic matter content. In Parmenac, the soil is a light-textured alluvial soil with a neutral pH (pH_{H2O} 6.4) and a low organic matter content. The soil at the Tavnik location is a heavy-textured pseudogley with a very acid pH (pH_{H2O} 4.2) and a medium organic matter content.

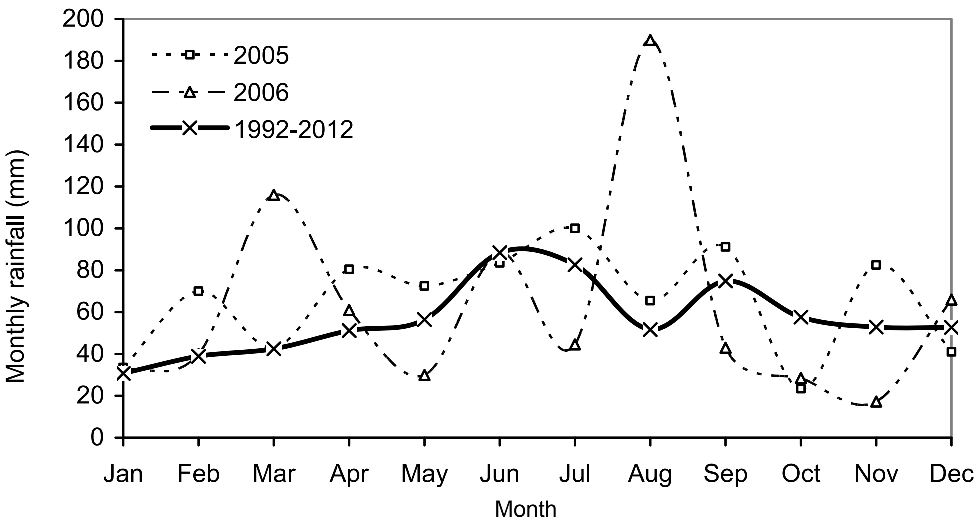

Figure 1. Monthly rainfall distribution for experimental years and 10-year (1992-2012) average

Mean monthly temperatures and rainfall data were recorded throughout the experimental ol years at a weather station located in Čačak (N 43^o 89' E 20^o 35'). As compared to the long-term average (1992-2012), the mean annual temperature was 0,3ºC lower i.e. higher in 2005 and 2006, respectively. Monthly rainfall (Figure 1) showed variations across growing season in experimental years, (April-September) particularly in 2006 year.

The experiments were laid out in a randomised block design with four replications. Each hybrid was sown in four rows per replication with 17 hills (each with two plants) per row at a spacing of 57 cm, making up a plant density of 50,000 plants ha^{-1}. Sowing was conducted in the first half of April in both years at all locations. Upon plant emergence, the crop was thinned to obtain the planned plant number. During the growing season, in both years, standard cultural practices without irrigation were used.

After harvest, in each plot, ear yield (60 plants) was measured and yield per ha was calculated at 14% moisture content. Laboratory analysis involved determination of grain moisture content at harvest (from the same sample, %), ear length (cm) and 1,000-kernel weight (g) for all hybrids per replication by counting out four random samples of 500 kernels and calculating their weight.

The results obtained were subjected to the factorial analysis of variance using F and LSD tests, and stability parameters were evaluated by regression analysis (Eberhart and Russell, 1966):

$Y_{ij} = m + b_i I_j + d_{ij}$ (i = 1,2,..t, j = 1,2,..s),

Where Y_{ij} – average of i-th hybrid at j-th location, m - overall average, b_i - regression coefficient for cultivar “i” in relation to the environmental index, I_j – environmental index (difference between the hybrid average at “j-th location and overall average), d_{ij} – deviation from the regression line of hybrid “i” at location “j”.

Standard t-test was used to test the significance of differences between regression coefficients and the average value (b_i = 1).

Results and discussion

The analysis of variance revealed significant differences in grain yield, grain moisture content at harvest, 1,000-kernel weight and ear length between hybrids belonging to different maturity groups and between locations (Table 1).

Table 1. Joint analysis of variance for grain yield, grain moisture content at harvest, ear length and 1,000-kernel weight (g)

		Grain yield		Grain moisture %		1,000-kernel weight		Ear length	
Years		2005	2006	2005	2006	2005	2006	2005	2006
Sources of variation	Df	MS	MS	MS	MS	MS	MS	MS	MS
Hybrids (H)	10	4.88**	7.09**	23.82**	25.04**	19.44**	20.25**	16.86**	12.58**
Locations (L)	2	296.2**	416.3**	111.3**	8.75**	351.3**	1010.2**	251.33**	192.02**
H x L	20	9.32**	5.68**	1.12**	0.97**	3.84**	2.27**	3.62**	3.51**

**F test significant at P≤0.01

The lowest average yield was produced by HY01, and the highest by HY06. No significant differences were found between the regression coefficients for all hybrids in the first year and the average value. The regression coefficient (b_i) was highest in medium-season HY06, and lowest in medium-early HY01. The regression coefficient of HY07 was closest to the mean value (1.007). The highest and significant deviation from regression was exhibited by HY08 (1.558). Half of the other hybrids showed significant values, whereas the other half showed negative values (Table 2.).

Table 2. Average grain yield (kg ha^{-1}) and stability parameters

Year	2005				2006			
Hybrid	*Yield*	$b_i \pm SE$	S^2d_i	R^2	*Yield*	$b_i \pm SE$	S^2d_i	R^2
HY01	8 531	0.746 ± 0.085	0.200*	0.987	6 650	0.951 ± 0.053	0.010	0.997
HY02	9 940	0.823 ± 0.143	0.713**	0.971	7 250	0.876 ± 0.057	0.020	0.996
HY03	10 860	0.907 ± 0.000	-0.077	1.000	7 661	0.892 ± 0.091	0.126*	0.989
HY04	10 010	0.879 ± 0.043	-0.007	0.998	7 532	0.876 ± 0.012	-0.046	0.999
HY05	10 522	1.069 ± 0.023	-0.057	0.999	7 990	0.980 ± 0121	0.259**	0.985
HY06	12 620	1.285 ± 0.102	0.329**	0.994	8 815	1.213 ± 0.081	0.089*	0.995
HY07	11 050	1.007 ± 0.000	-0.077	1.000	8 030	1.052 ± 0.067	0.045	0.996
HY08	11 740	1.185 ± 0.206	1.558**	0.971	9 211	1.134 ± 0.086	0.108*	0.994
HY09	11 192	1.073 ± 0.121	0.488**	0.987	9 190	1.023 ± 0.096	0.146**	0.991
HY10	11 583	1.120 ± 0.010	-0.73	0.999	8 562	1.148 ± 0.128	0.291**	0988
HY11	10 950	0.907 ± 0.079	0.168*	0.992	8 222	0.855 ± 0.189	0.702**	0.953
Average	10 818	1.000			8 101	1.000		

* Significant at $P \leq 0.05$, for $bi \neq 1$, $S2di \neq 0$

**Significant at $P \leq 0.01$, for $bi \neq 1$, $S2di \neq 0$

The b_i values in the second year did not differ significantly from the mean. The highest regression coefficient was determined in HY06 and the lowest in HY11. The regression coefficient of HY05 was closest to the mean. In the second year, the lowest and non-significant deviation from regression was exhibited by HY01, HY02, HY07. Similarly to the previous year, coefficients of determination were largely uniform and high. The values of the standard error of the mean of the regression coefficients suggest identical heterogeneity of b_i in both years.

Grain moisture content at harvest was highest in medium-late hybrids HY10 and HY11, with HY11 having the highest average value for the trait. At all locations, the lowest value was found in HY01 (Table 3).

In the first year, the linear regression coefficient was significantly lower in HY07, whereas no significant differences from the mean value were observed in the other hybrids. The value for this parameter was highest in HY09, and that of HY06 was closest to the average. As regards deviation from regression, the hybrids HY07, HY06, HY10 and HY11 showed no significant deviation from zero. In contrast, the values for the other hybrids were negative or significant. The regression coefficient in the second year was lowest in HY06, highest in HY04, and closest to the average value in HY10. Individual values were not significantly different from the average value in any hybrid. Most hybrids in the second year showed significant deviations from regression for grain moisture content.

Table 3. Grain moisture content at harvest (%) and stability parameters

Year Hybrid	2005 Moisture	$b_i \pm SE$	S^2d_i	R^2	2006 Moisture	$b_i \pm SE$	S^2d_i	R^2
HY01	22.79	0.875 ± 0.234	0.200*	0.933	21.41	0.671 ± 0.150	-0.062	0.952
HY02	25.11	0.803 ± 0.049	0.713**	0.960	22.55	1.390 ± 0.965	0.301**	0.647
HY03	25.73	1.300 ± 0.034	-0.077	0.999	23.82	0.755 ± 0.624	0.084	0.596
HY04	24.62	0.697 ± 0.020	-0.007	0.999	23.10	2.550 ± 1.289	0.590**	0.796
HY05	26.78	0.820 ± 0.234	-0.057	0.924	25.64	1.407 ± 0.100	-0.066	0.995
HY06	27.53	0.963 ± 0.163	0.329**	0.972	26.07	0.015 ± 0.716	0.134*	0.000
HY07	25.13	0.513 ± 0.156*	-0.077	0.915	24.77	1.813 ± 0.743	0.149*	0.856
HY08	29.14	1.242 ± 0.275	1.558**	0.953	26.63	0.648 ± 0.100	-0.067	0.977
HY09	28.40	1.329 ± 0.081	0.488**	0.996	27.07	0.505 ± 1.318	0.621**	0.127
HY10	28.88	1.309 ± 0.162	-0.73	0.985	27.43	1.179 ± 0.218	-0.052	0.967
HY11	29.37	1.150 ± 0.191	0.168*	0.973	27.97	0.074 ± 0.703	0.126*	0.010
Average	26.68	1.000			25.13	1.000		

* Significant at P≤0.05, for *bi*≠1, *S2di* ≠0

**Significant at P≤0.01, for *bi*≠1, *S2di* ≠0

Thousand-kernel weight was highest in HY08, and lowest in HY06. Significant differences in the trait were observed between hybrids as well as between locations. The highest and highly significant regression coefficient in the first year, relative to the average, was found in medium-late HY10, whereas medium-season HY08 and HY05 had significant values. The lowest highly significant b_i value was detected in HY02, and the value closest to the average in HY07. The hybrids HY09 and HY01 showed highly significant deviations from regression, whereas the other hybrids had negative values (Table 4).

Table 4. Thousand-kernel weight (g) and stability parameters

Year Hybrid	2005 1,000-k. weight	$b_i \pm SE$	S^2d_i	R^2	2006 1,000-k. weight	$b_i \pm SE$	S^2d_i	R^2
HY01	348	0.597 ± 0.230	0.597	0.864	330	0.392 ± 0.166	247.49**	0.981
HY02	380	0.504 ± 0.014**	0.504**	0.999	338	0.877 ± 0.046	-27.30	0.998
HY03	405	0.706 ± 0.015	0.706	0.965	368	1.303 ± 0.003	-50.63	1.00
HY04	395	1.049 ± 0.017	1.049	0.999	356	0.745 ± 0.024	-44.33	0.999
HY05	371	1.278 ± 0.029*	1.278*	0.999	335	1.154 ± 0.004	-50.35	0.999
HY06	392	1.185 ± 0.012	1.185	0.999	352	1.273 ± 0.020	-45.88	0.999
HY07	403	0.986 ± 0.032	0.986	0.999	357	0.820 ± 0.046	-28.04	0.998
HY08	408	1.313 ± 0.11*	1.313*	0.999	394	1.320 ± 0.097	50.65	0.986
HY09	356	0.934 ± 0.270	0.934	0.923	323	1.052 ± 0.065	-5.53	0.995
HY10	354	1.345 ± 0.014**	1.345**	0.999	330	1.215 ± 0.094	45.80	0.993
HY11	381	1.121 ± 0.038	1.121	0.999	362	0.846 ± 0.123	113.30*	0.975
Average	381	1.000			349	1.000		

* Significant at P≤0.05, for *bi*≠1, *S2di* ≠0

**Significant at P≤0.01, for *bi*≠1, *S2di* ≠0

In the second year, the regression coefficient was significantly different only in HY06, lowest in HY11, and closest to the mean value in HY04 and HY0. Similarly to the previous year, HY01 and HY11 exhibited highly significant and significant deviations from regression, respectively. With the exception of HY08 and HY10, the other hybrids showed negative values. The highest average value for ear length in the first year was found in HY08, and the lowest in HY01. The regression coefficient values in all hybrids did not significantly differ from the mean, with the hybrid HY09 being the closest to the average value. Most hybrids showed significant deviations from regression (Table 5).

Table 5. Ear length (cm) and stability parameters

Year	2005				2006			
Hybrid	*Ear length*	$b_i \pm SE$	S^2d_i	R^2	*Ear length*	$b_i \pm SE$	S^2d_i	R^2
HY01	18.0	0.392 ± 0.418	1.864**	0.468	17.6	0.076** ± 0.193	0.209*	0.133
HY02	20.2	0.877 ± 0.418	1.860**	0.815	20.3	1.121 ± 0.036	-0.106	0.999
HY03	21.2	1.303 ± 0.369	1.423**	0.926	20.4	1.195 ± 0.287	0.601**	0.946
HY04	20.9	0.745 ± 0.195	0.300*	0.936	20.2	0.717 ± 0.113	-0.006	0.976
HY05	20.9	1.154 ± 0.069	-0.081	0.996	20.5	1.281* ± 0.017	-0.114	0.999
HY06	21.4	1.273 ± 0.215	0.394**	0.972	20.3	1.478** ± 0.051	-0.094	0.999
HY07	20.6	0.820 ± 0.021	-0.131	0.999	19.7	0.742 ± 0.026	-0.111	0.999
HY08	22.0	1.320 ± 0.264	0.664**	0.961	21.4	1.119 ± 0.024	-0.112	0.999
HY09	21.8	1.052 ± 0.071	-0.079	0.995	21.1	1.349* ± 0.046	-0.098	0.999
HY10	22.1	1.215 ± 0.162	0.164*	0.982	20.9	1.368 ± 0.163	0.115	0.986
HY11	19,6	0.846 ± 0.252	0.589**	0.919	19.3	0.554* ± 0.122	0.014	0.954
Average	20.8	1.000			17.6	1.000		

* Significant at P≤0.05, for *bi*≠1, *S2di* ≠0

**Significant at P≤0.01, for *bi*≠1, *S2di* ≠0

In the second year, b_i was highly significantly higher than the average in HY06, and significantly higher in HY09 and HY05. The value for the parameter was significantly lower in HY01 and HY11, and closest to the average in HY08. The medium-early hybrids HY03 and HY01 showed significant deviations from regression, and negative values were observed in most other hybrids.

Discussion

Genotype adaptability and stability are useful parameters for recommending hybrids for known cultivation conditions. Eberhart and Russell (1966) proposed an assessment of cultivar response to environmental changes using a linear regression coefficient and variances of regression deviations. Cultivars are classified according to the value of their linear regression coefficients into those having *bi* less than, equal to, or greater than unity, as well as according to the value of the variance of regression deviations (equal to or different from zero). Namely, cultivars that have regression coefficients greater than unity would be more adapted to favourable growing conditions, those with regression coefficients less than unity would be adapted to unfavourable environmental conditions, and those with regression coefficients equal to unity would have an average adaptation to all environments. Furthermore, genotypes with variances in regression deviations equal to zero would have highly predictable behaviour, whereas those with regression deviation different from zero would have low predictability.

The regression coefficient for grain yield for all hybrids (except HY02 in 2005) was not significantly different from the mean, indicating adaptability of the test hybrids to the environment. The significantly different value of *bi* in HY02 in the first year suggests greater-than-average stability of this hybrid as compared to the other hybrids tested. Among medium-early hybrids, HY06 gave higher grain yields as compared to medium-late hybrids in almost all trials in both years, but also had higher values of the regression coefficient and showed mostly significant deviations from regression. The stability parameters indicate that this hybrid exhibits a specific response to the particular agroenvironmental conditions i.e. better adaptation to favourable environments. In terms of stability parameters, HY05 was comparable to the medium-early hybrids, with its grain yields at certain locations corresponding to those of late-season hybrids.

Most medium-early hybrids give low yields, along with generally favourable values of stability parameters i.e. better adaptation to unfavourable conditions. The results of many authors suggest that hybrids with higher average yields have better adaptation to favourable agroenvironmental conditions, with no linear trend observed due to significant regression deviations i.e. low-yielding hybrids show better performance under unfavourable conditions and allow higher predictability of their response due to relatively low values of deviation (Petrović et al. 1988; Yue et. al 1990, 1997; Jocković et al. 2005; Boćanski et al. 2000). The hybrids belonging to low maturity groups have higher adaptability, but show a low response to the environment and, hence, frequent inability to make use of favourable conditions (Troyer 2005).

Alwala et al. (2010) reported that genotypes with high regression coefficients are considered high-yielding, as opposed to low-yielding genotypes (hybrids) with low values of the regression coefficient. Likewise, genotypes having a high value of S^2di are considered highly unstable, whereas those with low values as highly stable. The same authors underlined that regression analysis, although widely used in the previous period, provides useful information on genotype stability. A broader picture of grain yield cannot be completely predicted by this model. Although deviations from regression can be used as a stability parameter, the regression coefficient cannot be taken as a yield substituent due to the absence of significant correlation between regression coefficients and yield.

Scapin et al. (2000) recommended that hybrids having *bi* >1, S^2di different from zero, high yields and high values of the coefficient of determination *bi* regardless of the significance of S^2di be used under favourable conditions involving a high level of technology. In addition, hybrids with *bi* =1, S^2di = 0, and a high coefficient of determination have an average capacity for adaptation to all environments and are highly predictable. Eberhart and Russell (1966) described them as potentially ideal hybrids, since they maintain good performance under unfavourable growing conditions. Genotypes with high mean yields and specific adaptability to unfavourable environments are very rare (Scapin et al. 2000; Mustatea et al. 2009).

Magari et al. (1997) used the analysis of stability parameters for the rate of grain moisture loss at maturity to suggest that, given the high value of genotype x environment interaction, the response to known environmental conditions should be individually assessed for each hybrid or group of related hybrids, as confirmed by the results of the present study. The association found by Ordas et al. (2006) between a high moisture percentage at harvest and lack of hybrid adaptability to a given agroenvironment was confirmed by the values for this trait in hybrids from high maturity groups i.e. by the analysis of their stability parameters. Petrović et al. (1988)

detected a high regression coefficient for moisture content in high-yielding hybrids, indicating that a reduction in moisture percentage results in increased stability for the trait. An estimation of this parameter is largely dependent upon weather conditions during the experimental years.

The significance of hybrid x environment interaction for 1,000-kernel weight was also reported by Mann et al. (1981), Kee (1994) and El-Sheribreny et al. (2006), whereas Gyanendra et al. (1996) found no interaction between the trait and the environment. The behaviour of most hybrids regarding this parameter was not uniform; hence, the *bi* value showed inconsistency, particularly across years. With the exception of HY01 showing significant deviations from regression, HY09; HY11 in the first and second years, the other hybrids had non-significant deviations. The association between lower average values of a particular trait and greater than average stability was also observed in ear length. Regardless of maturity group, HY01 and HY11 with low values for this trait in almost all years had significantly lower regression coefficient values. Conversely, the hybrids giving high values for the trait, with HY03 and HY06 as representatives of lower maturity groups, had coefficient values greater than 1 and, occasionally, significantly higher values. Much greater heterogeneity in *bi* was observed in the first year, which was more favourable, resulting in more pronounced differences among genotypes in their response to environmental conditions. This was also confirmed by significant deviations from regression, suggesting that more favourable conditions induced strong hybrid x environment interactions.

Conclusion

Significant differences in grain yield, grain moisture content at maturity, 1,000-kernel weight and ear length were observed between hybrids, as well as between locations. The traits analysed showed significant interaction with the environment. The hybrids with higher mean values of the traits, regardless of maturity group, generally exhibited sensitivity i.e. adaptability to more favourable environmental conditions as compared to those having lower mean values. Regression coefficients for grain yield did not significantly differ from the mean (except in one case). Therefore, in terms of this parameter, the hybrids were found to be adapted to agroenvironmental conditions. Among medium-season hybrids, HY06 gave higher yields and had less favourable values of stability parameters compared to medium-late hybrids. Hybrids belonging to FAO maturity groups 600 and 700 mostly exhibited unfavourable values of stability parameters for all traits, showing a specific response and better adaptation to favourable environmental conditions, and gave higher average yields compared to early hybrids. HY01 and all hybrids from FAO 400 group gave lower average yields, and were more stable than the other hybrids.

Given their higher yields and better response to favourable environmental conditions compared to the early-maturing hybrids, medium-late hybrids can be recommended for intensive cultural practices and low-stress environments. Medium-early hybrids i.e. FAO group 400 hybrids, being more stable, can be recommended for less favourable agroenvironmental conditions including low-intensity cultural operations and stressful environments.

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